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Study of the Actual Coverage Area of the Satellite Signal Ka-Sat RUSSIA

Alexey Lagunov, IEEE Member N80681383, Dmitry Fedin, Anatoliy Tyagunin, Nadegda Podorozhnyak, Vitaly Pozdeev, Vitaly Glavatskih, Pavel Danilochkin

***Abstract*: Obtained by the authors in 2013 data about the actual coverage by signal of 75th and 76th beams of satellite Ka-Sat in the Arkhangelsk Region, the Murmansk Region and Nenets Autonomous District, the Barents and White Seas does not match with the theoretical coverage area. In 2014 the authors organized a new expedition in order to receive new data. The data obtained were processed using algorithms of Ian C.Briggs. The new model of signal coverage was constructed. This model largely matches with the theoretical coverage area. The difference is that in the actual coverage area the signals 75th and 76th of beam are overlap.**

Keywords: Ka-Band, Ka-Sat, VSAT

I. Introduction

Currently, the Russian Federation, the priority is development of telecommunications. To the north of Russia and the Arctic is the most appropriate use of space communications. Ka-band - a promising range of frequencies and millimeter waves, allowing end users to provide multimedia services and broadband Internet access. In now time, spacecraft communications with home-made Ka-band transponders are in production.

KA-SAT has represented a new generation of High Throughput Satellites (HTS) with the largest number of spots delivering a capacity of 90 Gb/s for a wide variety of services ranging from internet access in homes, to satellite news gathering and domestic broadcasting [1],[2].

HTS systems found quite widely application in Western Europe. But in Russia these systems are rarely used. One of the problems of it is the lack of data on the actual signal coverage in Russia.

In the northern latitudes of Russia, there are two beams of a foreign satellite Ka-Sat, partially covering the territory of Arkhangelsk and Murmansk regions and the NAO and the Barents and White Seas. The signal strength in these areas and cover only known in theory. In practice, not referring to the prevalence of ground equipment on the territory of the Russian Federation, have not been studied possibilities of technology-based communication Ka-band.

Northern (Arctic) Federal University named after M.V. Lomonosov, 163002, ul. Severnaya Dvina Emb. 17, Arkhangelsk, Russia; http://www.narfu.ru

Alexey Lagunov (phone: 7-8182-683778, e mail: a.lagunov@narfu.ru)

Dmitry Fedin (e mail: d.fedin@narfu.ru)

Anatoliy Tyagunin (e mail: a.tyagunin@narfu.ru)

Nadegda Podorozhnyak (e mail: hikari777@mail.ru)

Vitaly Pozdeev (e mail: v.pozdeev@narfu.ru)

Federal State Unitary Enterprise "Satellite Communications Company", 8, bld. 6, 1st Goncharny pereulok, Moscow, 115172, Russia, http: http://eng.rscc.ru/

Vitaly Glavatskih (e mail: vglavatskikh@rscc.ru)

Pavel Danilochkin (e mail: pdanilochkin@rscc.ru)

The aim of this work is to reveal the possibilities and limitations of using this range in the far north of Russia.

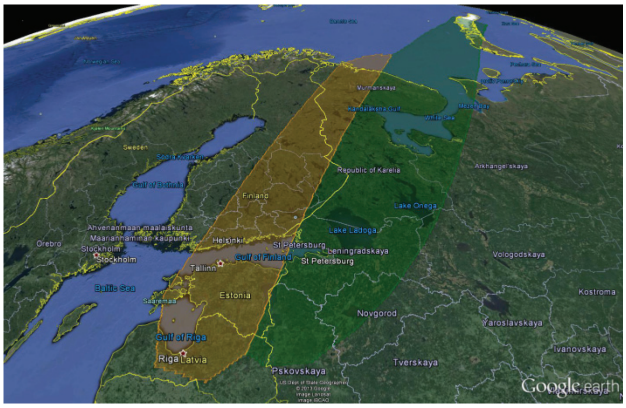

Fig.1. 75 and 76 beams.

Obtained as a result of the expedition coverage area does not match with the theoretical one (Fig.1) [3]. In 2014 the authors organized a new expedition in order to get the new data. This article is focused on the results obtained in the expedition.

II. Peculiarities of Ka-band Satellite Signals Attenuation

The last few years we saw an active commercial development of Ka-band signals with regard to the systems of fixed satellite communication and broadcasting. This is due to two main factors. The first relates to the problem of international coordination of new geostationary satellites in the Ku-band, the second one does to with the desire to realize utmost large satellite capacity in order to minimize the cost of transferring a unit of information. In addition, to implement a high-definition broadcasting and even to move to the 3D broadcasting it requires an increase in the frequency resource of satellites. Without transition from Ku- to Ka-band one cannot solve this problem [4].

The reality of these factors is confirmed by the general world development tendency of the information society. The fact that the volume of information generated by the latter grows steadily and so does the necessity to transfer it (global traffic doubles yearly during recent years). Because of this there is a desire to increase bandwidth worldwide and, in particular, one can feel a deficit of the satellite capacity [4].

One of the main problems of signal attenuation when using the Ka-band signal is due to weather conditions, which, in the end, determine the attainable availability of satellite channels that is the quality and reliability of the final service.

It is difficult and voluminous issue to strictly predict the attenuation of the satellite radio channel and it requires

numerous calculations. Apparently, there is no other issue that would has so many studies devoted to it and included in the recommendations of the International Telecommunication Union (ITU). As a basis we take recommendations ITU-R [5]. Recommendations of ITU-R P-Series (Propagation of radio waves) [6] is a wide list of factors that affect the attenuation of satellite signals in the atmosphere. These include: atmospheric gases (P.676, P.1510); sand and dust storms (P.618); clouds (P.840); snow, ice (P.618); tropospheric scintillation (P.618, P.453); rain (P.618, P.837, P.839).

Each of these phenomena has own characteristics depending on frequency and geographic position angle. Typically, at angles of elevation exceeding 10° only gases, rain, clouds, and, possibly, flicker attenuation will be significant depending on the propagation conditions.

Recommendation ITU-R P.840-5 (02/2012) [5] has a plot of the dependence of water drops linear attenuation at different temperatures on the frequency (Fig.2). At the attenuating in the cloudiness one must use the curve corresponding to 0°C.

The graph shows that at frequencies of Ka-band attenuation in the clouds lies within the range from 0.5 to 1 (dB / km) / (g / m3).

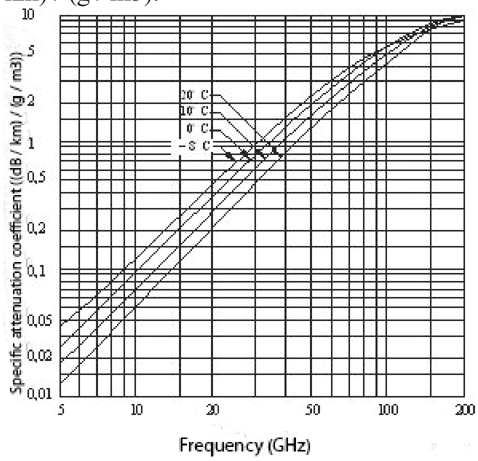

Fig.2. Dependence of water drops linear attenuation at different temperatures on the frequency

In addition to the atmospheric phenomena in ITU-R Recommendations R.618 [7] there are the factors influencing the signal propagation from the satellite to the ground stations. These factors are associated with the physical laws of wave propagation in the atmosphere and include:

- signal loss due to the beam divergence of earth station antenna caused by normal refraction in the atmosphere;
- decrease in the effective antenna gain due to phase decorrelation at the aperture of the antenna caused by irregularities in the structure of the refraction index;
- relatively slow fading due to the deflection of the beam caused by large-scale changes in the refractive index; more rapid fading (scintillation) and changes in the angle-of-arrival caused by small-scale changes in the refractive index;
- possible limitations of bandwidth caused by multiple scattering or multipath phenomenon, especially in digital systems of high capacity;
- attenuation caused by the local environment close to the ground station (buildings, trees, and so on)
- short-term changes in attitudes of attenuation levels at the frequencies of up and down, affecting the accuracy of adaptive ways of dealing with fading;
- for non-geostationary satellite (non-GSO) systems - the effect of changes in the elevation angle of direction to the satellite;
- Faraday rotation: while propagating of a linearly polarized wave in the ionosphere there is a progressive rotation of the polarization plane;
- dispersion leading to delay of transmitted signal differentiated by bandwidth;
- additional time delay.

Because of the large number of factors the actual prediction of signal propagation in a particular area is done separately by means of specially designed software systems.

III. EXPERIMENTAL STUDY

The study was conducted in the form of a car expedition route through 75 (green) and 76 (orange) beams. The expedition was supported by the Federal State Unitary Enterprise "Russian Satellite Communications Company". For the study, we used the following equipment (Fig.3): Terminal C-Comsat iNet Vu Ka-75 V Ka Platform, Controller CTR - 7024 - 10C, Satellite modem Tooway Surfbeam2, Transceiver 3 W, Spectrum Analyzer NI PXI 5660 as part of the chassis based on NI PXI 1042Q controller with NI PXI 8108 [8], Own software to automatically collect telemetry data from the modem and controller, Weather station Oregon Scientific WMR 88.

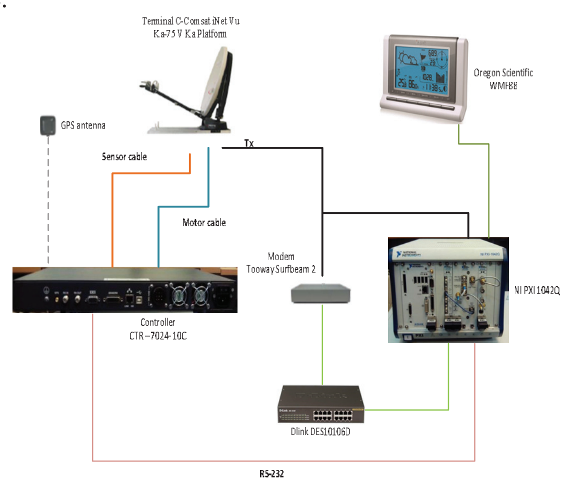

Fig.3. Circuit connection of the equipment.

Measurements were carried out approximately every 50 km (Fig.4). At the point of measurement was performed antenna pointing, telemetry collection for half an hour and sending to a central server. Telemetry was the testimony of a modem controller, a spectrum analyzer, the weather station. Co-starring the results of the speed test internet

connection. Channel data was kindly provided by Federal State Unitary Enterprise "Satellite Communications Company".

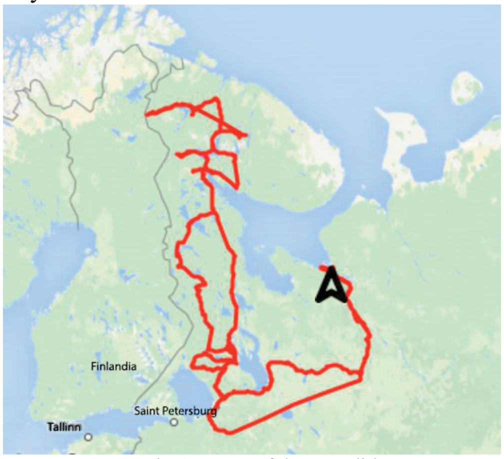

Fig.4. Route of the expedition

IV. MATHEMATICS MODEL

Contour maps are rather useful in the evaluation and interpretation of geophysical data when being produced by the help of a computer. According to data received from our researching, the areas showing how beams cover some regions were drawn and on the pictures below they are green and orange ones and calculated using the method [9].

Methods for the production of contour maps are variation of either weighting or function fitting or both. The main problem facing the maps creation is one of the problem of interpolation that is to define a set of values at the points of a regular grid, so that a grid point value tends to an observational value if the position of observation tends to the grid point. The problem of interpolation in two dimensions has led to the piecewise polynomial fit, or spline. The optimum properties of the spline fit can be obtained in two dimensions by solving the differential equation equivalent to a third-order spline. This is equation which describes the displacement of a thin sheet in two dimensions under the influence of point forces. The 'boundary conditions' are not only at the ends or boundary, but within the region of interest. The solution is forced to take up the value of the observation at the point of observation in two dimensions. The equation is solved numerically.

The principle of minimum curvature is used to deduce the normal difference equations. The total squared curvature is constructed directly in terms of elements of the set of grid point values

$$u_{i,j} \equiv u(x_i, y_j), x_i = (i-1)h, y_j = (j-1)h, i = 1, \dots, I, j = 1, \dots, J, \quad (1)$$

where h is the grid spacing. The discrete total squared curvature is

$$C = \sum_{i=1}^{I} \sum_{j=1}^{J} (C_{i,j})^2, \quad (2)$$

where $C_{i,j}$ is the curvature at (x_i, y_j). $C_{i,j}$ is a function of $u_{i,j}$ and some neighboring grid values; the exact set depends on the accuracy with which the curvature is to be represented.

To minimize the sum C, the functions

$$\frac{\partial C}{\partial u_{i,j}}, i = 1, \dots, I; j = 1, \dots, J, \quad (3)$$

are set equal to zero. The resulting equations determine a set of relations between neighboring grid-point values, one relation for each grid point. In one dimension the simplest approximation to the curvature at x, is

$$(u_{i+1} + u_{i-1} - 2u_i)/h^2,$$

and in two dimensions at (x_i, y_i), it is

$$C_{i,j} = (u_{i+1,j} + u_{i-1,j} + u_{i,j+1} + u_{i,j-1} - 4u_{i,j})/h^2 \quad (4)$$

Along edges and rows one from the edge, and near corners, different expressions for the curvature are used. These special cases are also included in the total for C. Away from the edges, (4) shows that a grid point value $u_{i,j}$ occurs in the expressions for,

$$C_{i,j}, C_{i+1,j}, C_{i-1,j}, C_{i,j+1} \; and \; C_{i,j-1}$$

Thus, only these need to be considered when equation (4) is used. Using (2), (3), and (4) the common difference equation for the biharmonic equation results:

$$u_{i+2,j} + u_{i,j+2} + u_{i-2,j} + u_{i,j-2} + 2\big(u_{i+1,j+1} + u_{i-1,j+1} + u_{i+1,j-1} + u_{i-1,j-1}\big) - 8\big(u_{i+1,j} + u_{i-1,j} + u_{i,j-1} + u_{i,j+1}\big) + 20u_{i,j} = 0 \quad (5)$$

For the edge $j=1$, the difference equation is

$$u_{i-2,j} + u_{i+2,j} + u_{i,j+2} + u_{i-1,j+1} + u_{i+1,j+1} - 4\big(u_{i-1,j} + u_{i,j+1} + u_{i+1,j}\big) + 7u_{i,j} = 0 \quad (6)$$

The method of constructing an iterative matrix. The set of linear algebraic equations (5), (6), and others are best solved iteratively. Given an approximate set of $u_{i,j}$, a new set is obtained by making $u_{i,j}$ the subject of equations (5) and (6) and others. For example, (6) gives

$$u_{i,j}^{p+1} = \big[4\big(u_{i-1,j}^p + u_{i,j+1}^p + u_{i+1,j}^p\big) - \big(u_{i-2,j}^p + u_{i+2,j}^p + u_{i,j+2}^p + u_{i-1,j+1}^p + u_{i+1,j+1}^p\big)\big]/7, \quad (7)$$

where the index p indicates the pth iteration. Starting values must be given, and one suitable method is to use the value of the nearest observation or a weighted sum of neighboring observations.

Iteration matrices which give faster rates of convergence than that defined by (7) are known, but are not described here. The proof of the existence of a solution to the linear equations is omitted.

The measure of smoothness, $C = \sum (C_{i,j})^2$ is a function of h and the precision of the approximation for $C_{i,j}$. Because the linear equations are deduced from the principle of minimum C, for a given h and for a given definition of curvature, the resulting grid-point surface is smoother than, or as smooth as, any other grid-point surface. Two contour maps produced by different means but using the same data, can be compared for smoothness by digitizing the map, if necessary, and calculating the total curvature C. The map with the lower value of C is usually the more acceptable, and delineates trends more clearly.

Nothing will be said here about the convergence of the grid point values or of C, as the grid spacing tends to zero. However, for a given grid-spacing, the method gives the smoothest possible contour map, and it can be used with some confidence as a representation of the given data.

There are many different methods of drawing the contours once the grid surface has been found. The

method used in the examples involves a four-point cubic interpolation between grid points to find contour cuts, and then a cubic spline to join the cuts. The observations art not used. This is the weak link in the present scheme. Improvements can be made by using the observations or by using two-dimensional cubic interpolation over a grid square. The overall success of the application of minimum total curvature warrants the undertaking of further work in the improvement of details.

V. FINDINGS

Use the method of Section 4 for the construction of coverage.

75th beam captures the north-western part of the Arkhangelsk region, Onega region and the south-east part of the Republic of Karelia. The green beam is characterized by high Rx SNR, especially in the Onega region (Fig.5).

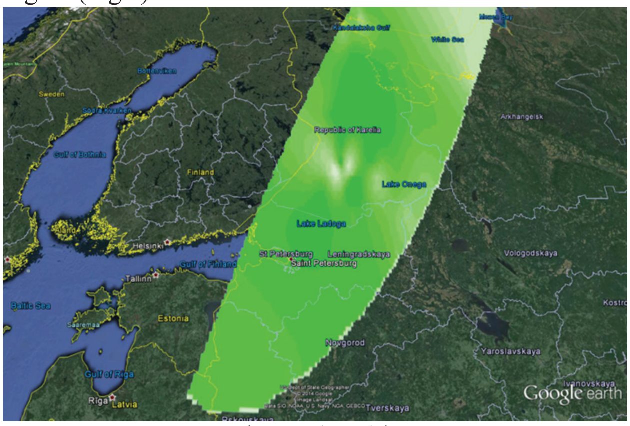

Fig.5. 75 (green) beam.

This is not surprising, since the northern areas have a relatively low elevation angle of the antenna (12-14 degrees), while we studied area is not characterized by the presence of high obstacles in the direction of antenna pointing. Horizon in these places clean and well looked, and nothing prevents the signal.

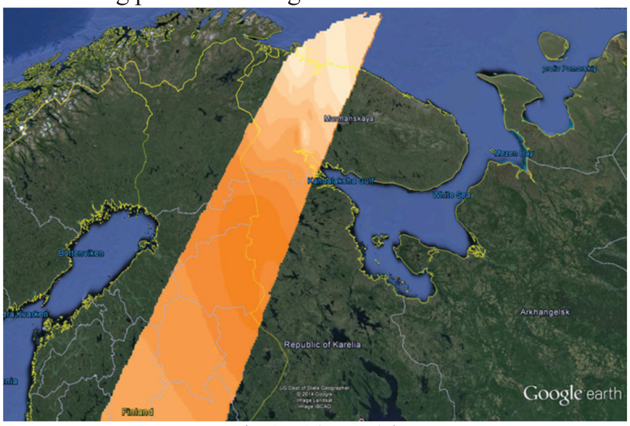

Fig.6. 76 (orange) beam

76 (orange) beam (Fig.6) was more rich in interesting facts. It was found that with a beam width of about 200 km, it is almost halfway to the east is blocked 75 beam. Moreover, the signal green beam in the orange is not inferior to the level of the signal orange beam. A 76 beam covers the territory of the Republic has Karelia and the Murmansk region in which there are a variety of different heights, which interfere with the signal. Comparison of actual coverage (Fig.5,6) with theoretical (Fig.1) shows that they are practically the same.

VI. THE MAIN PROBLEM OF APPLICATION OF KA-VSAT IN THE NORTHERN LATITUDES

Unfortunately, there were some drawbacks:

- Low elevation
- Hilly and highland
- The dependence of the signal on the weather conditions
- The need to be selected carefully place the antenna, or to increase the height of the antenna
- It is desirable to use high-power transmitters (more than 3 Watts)

In northern elevation is low enough (12-14 degrees), so the presence of even small elevations in the direction of pointing the antenna reduces the signal strength. This is especially critical for the Back channel as the transmit power is small and as a result, the signal can not pass through the obstacle. Therefore, for high-quality guidance has to carefully choose the place of installation. Also plays a big height of the antenna. In our case, it was only 2.4 meters. At this altitude, most of the obstacles (hills, hills, mountains) prevent direct view of the satellite. Increasing the height of installation allows you to bypass this limitation.

VII. CONCLUSION

As a result, during two field expeditions in 2013 and 2014 we constructed the actual coverage map of 75th and 76th beams signals of satellite Ka-Sat in the Arkhangelsk Region, the Murmansk Region and Nenets Autonomous District, the Barents and White Seas. The coverage map is basically the same with the theoretical coverage map. The difference is that in the actual coverage area of the signals 75thth and 76thth beams are overlap.

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